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ABSTRACT

This study attempts to raise and answer the question as to whether lateral specialization of the brain could explain some of the differences in persons at different stages of intellectual development from birth to adulthood according to Piaget's theory of individual development via sequential, qualitatively different stages. Electroencephalographic measures were used as indicators of hemispheric specialization of concrete and formal persons. The brain activity of six concrete and seven formal subjects was monitored from the central and parietal regions of the cerebral cortex while the subjects were responding to mental tasks. Hemispheric asymmetry was determined by the ratios (left/right) of the alphapowers from homologous leads. Logarithmic ratios of formal subjects were greater than concrete subjects indicating more lateralization of function for formal persons, especially on the logic task. (Autnor/KS)

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An EEG Investigation of the Differences in the Hemispheric Specialization of Formal and Concrete Operational Persons

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There is an abundance of evidence supporting the view that the hemispheres of man's brain are specialized to perform different cognitive functions. Surgeons sectioned the forebrain commissures (corpus callosum, anterior and hippocampal commissures, massa intermedia) for control of intractable seizures, producing persons with two isolated half-brains, each of which could carry out the cognitive processes of the type for which it was specialized. [1,2,3,4] In these patients the left hemisphere was capable of speech, writing, and mathematical calculation, but was severely limited when dealing with spatial relationships. The right hemisphere was found to be able to process only a few nouns, but it could easily perform tasks involving complex spatial relationships and music patterns. More recent research on normal persons also serves to establish the validity of this theory of lateral specialization. Using dichotic listening techniques, Kimura [5,6] found the left hemisphere

on normal right-handed persons to be superior for words, nonsense syllables and backward speech, whereas the right hemisphere was superior for melodic patterns and non-speech human sounds.

Visual tachistoscopic studies have also revealed asymmetries in the functioning of the hemispheres[7]. These studies confirm the right hemisphere superiority for spatial perceptions. Using this technique, Cohen[8] hypothesized that the left hemisphere processes stimuli in sequence while the right hemisphere analyzes stimuli in parallel. Levy[9] feels that the two hemispheres, working on the same task, may process the same sensory information in distinct ways, and that these may at times be mutually antagonistic.

Galin and Ornstein[10,11,12] have demonstrated the usefulness of electroencephalography to assess hemispheric specialization in normal subjects. Their results show the alpha band of the brain wave spectrum to be the best indicator of asymmetry, with the temporal, parietal and central regions the best recording sites. Using the ratio of left hemisphere alpha power to right hemisphere power as their measure of asymmetry , they found lower alpha power ratios for verbal tasks than spatial tasks.

The usefulness of this method of research has been supported by Butler and Glass [13], McKee, Humphrey, and McAdam [14], and Dumas and Morgan [15]. Their findings fit the general scheme of things: the left hemisphere functions in an analytic, linear mode, whereas the right hemisphere functions in a holistic, gestalt mode.

An interesting question related to these findings doesn't seem to have been raised. Piaget has established a theory of intellectual development which states that individuals progress sequentially through a series of qualitatively different stages of intellectual development from birth to adulthood. These stages (with their approximate age ranges) are designated as: sensorimotor (0-2 years), preoperational (2-7 years), concrete operational (7-11 years), and formal operational (12-15 years and older) [16,17]. Over the past twenty-five years much research has been based on this theory and its many aspects. However, little is known of the role brain maturation plays in cognitive development.

The present study attempted to raise and answer the question as to whether lateral specialization of the brain could explain some of the differences in persons at different stages of intellectual development. The differences between formal operational and concrete

operational college students were investigated. More specifically, using the concepts and methodology developed by Galin and Ornstein [10,11], this study found differences in hemispheric brain activity of concrete and formal persons actively engaged in the solution of the same cognitive tasks.

METHOD

Subjects

Twenty-eight university students consisting of nine males and nineteen females ranging in age from eighteen to fifty-five were selected as subjects for this study. They were all non-science majors, with twenty of them in elementary education, which accounts for the high percentage of females.

From the twenty-eight subjects taking the Piagetian tests, eleven concrete and nine formal individuals were randomly selected to participate in the second part of this study. Only concrete and formal subjects (transitional subjects were eliminated) were used to insure a distinct difference in the stage classification of subjects. Of the eleven concrete and eight formal individuals, nine concrete and eight formal persons agreed to participate in this stage of the study and were

randomly assigned a time to appear for the EEG session. Because of illness or other unknown reasons three concrete and one formal subject failed to report, resulting in a final sample of thirteen students consisting of four female and two male concrete subjects and five female and two male formal subjects.

Instruments

Two types of instrumentation were used in this study. The first consisted of the set of Piagetian tasks used to classify the subjects. The second was a series of mental tasks administered while EEGs were being obtained.

A battery of Piagetian tasks was administered to the subjects and the results used to classify them as concrete or formal thinkers. The Piagetian tasks consisted of (1) the conservation of volume using metal cylinders [17] (2) separation of variables, and (3) equilibrium in the balance. The latter two of these were tasks used by Inhelder and Piaget [15] to establish the characteristics of concrete operational and formal operational thought.

A set of seven tasks was administered while EEG recordings were being made. The first of these was attention to breathing where the subject was instructed

to clear his mind, relax, and focus his attention on his breathing with his eyes open and fixed on the blank white sheet of paper displayed before him. This task was included primarily to relax the subject, acclimate him to the situation, and check the quality of the recording. It was also included as a neutral task to assess any possible differences in the baseline hemispheric lateralization of concrete and formal persons while resting. This task was repeated later to assess the reliability of the EEG results. The second task, mental arithmetic, required mental multiplication of five one digit numbers. The subject was told that he would be shown the five numbers but was not instructed to multiply them in a specific order. He was instructed to give his result verbally when he had completed the task. Later during the session this task was repeated with five different numbers to check the reliability of the EEG results. The average of these two episodes was used for the data analysis. The third task involved listening to the reading of a passage. This should have elicited the processing of verbal stimuli which contain as few, if any, verbal images. The subject was instructed beforehand that he would subsequently be asked a few questions on the content of the material read to encourage

the most efficient processing of the material for recall. The fourth task used was a spatial task taken from the Modified Minnesota Paper Form Board Test [16]. The subject was presented with a drawing of a sectioned figure and instructed to choose by visual inspection which of five assembled figures could be constructed from these sections. Specific designs were chosen which would involve as little verbal encoding as possible.

The previous tasks are similar to those used by Galin and Ornstein in their work. The remaining three tasks are unique to this study in that they are tasks classified as requiring concrete or formal operational thought. The fifth task assessed the ability to conserve volume using cubes [17]. The subject was shown a sketch of an apartment building with the dimensions 3 X 3 X 4. He was told that the apartment was destroyed and that the owner wants to rebuild it so as to have the same number of 1 X 1 X 1 cubic rooms as the original building. The subject was shown the new base and asked how tall the building will be. The EEG was coded to clearly indicate the segment of EEG recorded while the question was being answered. The final two tasks were classified as tasks requiring formal operational thinking for complete solution. The subject was shown a box with four

buttons and a light [19] . With the buttons concealed from the subject's view the experimenter pushed a combination of buttons which caused the light to come on to demonstrate that the bulb would light. He was given the box and instructed to determine how to light the bulb. When he found a correct combination of buttons he was asked if there were any other correct combinations. The complete solution of this task required a systematic examination of all possible combinations. Only a formal operational person is capable of the complete analysis. This task was chosen because it required little muscular movement and thus produced less EEG artifacts than other Piagetian formal tasks. The seventh task was a logic problem. The subject was instructed that after reading three statements he would be given five statements to evaluate as correct or incorrect based upon the three original statements. According to Piagetian theory, formal operations are required to correctly solve this type of problem.

Experimental procedure

Upon arriving at the EEG laboratory the experimental procedure was carefully explained to the subject and his written consent as a subject was obtained. Electrodes

were placed according to the ten-twenty system of the Internation Federation 20 at C_3, C_4, C_z, P_n, P_4 with a ground electrode on the forehead. Channels of EEG were recorded from C_3 - C_z, C_4 - C_z, P_3 - C_z, a nd P_4 - C_z. Using a Grass Model EZMID Electrode Impedence Meter, the interelectrode impedence was determined to be well below the accepted 10,000 ohms level. The subject was then seated in a comfortable lounge chair in a booth so that only the person administering the tasks was visible. The booth served to eliminate external visual and auditory stimuli that might otherwise distract the subject. Prior to starting each task, the task was described by the experimenter to orient the subject to the exercise. He was told that the correct answers were not important and in fact would not be recorded. This was done to help the subject relax and overcome anxiety. The tasks to be performed were displayed on a vertical board directly in front of the subject. This served to minimize head and eye movements.

The EEG data were recorded simultaneously on a Grass Model 79D polygraph and a Hewlett-Packard Model 3960A FM 4-track tape recorder. The paper record produced by the polygraph served several important functions. First, it provided a visual record of the data that could be

used for manually editing the data for unwanted artifacts. It was also valuable in verifying segments during computer analysis of data. As the data were being recorded, the paper record was used to note any significant events that might be of interest later (e.g. muscle artifacts due to movement) and the timing of responses to questions.

The data analysis proceeded through a sequence of three stages. The tape was first played into a PDP computer and the segment between the predetermined DC code levels was identified and stored on discs. Next the computer displayed each one second interval of data on a screen as instructed by the operator. The experimenter proceeded to inspect the recorded signals second by second instructing the computer to either accept or reject that given interval. Once all of the data were edited, they were then analyzed by a program which performed a Fast Fourier Transform and power spectral calculation on each channel of data for each one second segment. The spectral power values were then averaged together in five groups (1-3 H_z, 4-7 H_z, 8-13 H_z, 14-20 H_z, 21-29 H_z) which correspond to the standard frequency bands of brain waves. Based on findings of Doyle, Ornstein, and Galin (in press), the alpha band (8-13 H_z) was used for future analysis. Various powers and ratios of average powers

for (C_3/C_4) and (P_3/P_4) were printed for further analysis. Also, the computer printed out the (C_3/C_4) and (P_3/P_4) alpha ratio for each second of data.

Following the procedure of Galin Ornstein, this study used the ratio of the alpha power from the left hemisphere to the alpha power from the right hemisphere for both the central and parietal regions of the cerebral cortex. These are designated as (C_3/C_4) and (P_3/P_4). In this study the ratio of the average power was computed for each second of the task and the average of the ratios was then calculated. The first ratio is the better indicator of the site of activity across time.

In order to meet the normality assumption underlying analysis of variance, a logarithm transformation was performed on the ratios.

RESULTS

The two dependent variables were (1) the log transformed ratios of the average alpha powers from the central region and (2) the log transformed ratios of the average of the alpha powers from the parietal region. A 2 (Groups) X 7 (Tasks) analysis of variance of the log of transformed ratios from the central region resulted in no significant differences for main effects ($F=1.445$,

F=.861) or interaction (F=1.573). The means and standard deviations for the 14 cells are presented in Table 1. There was a trend toward greater left hemispheric activity compared to right for the formal subjects. This can be seen clearly in Figure 1.

Insert Table 1 and Figure 1 about here

Data revealed that for nearly all subjects, the listening task evoked the greatest alpha power.

A 2 (Group)X 7 (Tasks) analysis of variance on the log transformed ratios from the parietal region resulted in a significant difference between groups, with the concrete operational persons having higher log ratios than the formal persons ($F=6.74$, $p < .03$). There were no task ($F=.455$) or interaction differences ($F=.617$). The means and standard derivations for the 14 cells are presented in Table 2. Figure 2 clearly shows that formal subjects displayed greater left hemisphere activity on all tasks but the analog.

Insert Table 2 and Figure 2 about here

A t-test of differences between means for each task indicated this overall difference resulted primarily from differences on the logic task with the concrete persons having significantly higher log ratios ($t=3.00$ $p < .02$) than formal persons.

Finally, the Wilcoxon Signed-Rank test was used to assess differences in the tasks for concrete and formal subjects considered separately. For concrete subjects, the logic task resulted in greater left hemispheric cognitive activity than either the spatial or conservation of volume tasks. For formal subjects the arithmetic task was statistically more of a left hemisphere task than the spatial task. Also, the conservation task evoked significantly greater left hemisphere activity than the analog task. Of possible importance was the finding that the formal persons displayed reversed effects when the central region and parietal region data were compared. The central region data showed the spatial task more analytic than the logic and conservation of volume tasks whereas the parietal region data showed the opposite results. These results would imply that localization of mental functions within the hemispheres of the brain must be considered as well as lateralization.

When the concrete and formal groups were pooled,

the arithmetic task was significantly more left hemispheric than the spatial task, which is in agreement with other studies. The surprising finding was that the spatial task was significantly more of a left hemispheric task than was the listening to reading task. As was mentioned earlier, the listening task was the task with least cognitive activity for nearly all subjects. It would appear that the subjects did not concentrate while listening and therefore, the brain went into a right hemisphere daydream.

DISCUSSION

A look at the results from both regions of the cerebral cortex reveals that for these particular tasks, formal persons were relatively more left hemispheric in their cognitive functioning than were concrete persons. This was most noticeable in the conservation of volume and logic tasks. It is of special interest that only on the analog task did the concrete persons have a lower alpha power ratio than the formal persons. Comparison of tasks supported this and also revealed that the arithmetic task was more of a left hemisphere task than the spatial task while the listening to reading task was less of a left hemisphere task than the spatial task.

It appears from these data that formal operational persons are more lateralized for cognitive functioning than concrete operational persons.

Choice of Electrode Placement

An electroencephalogram was recorded for each subject symmetrically from the left and right side of the central and parietal regions of the cerebral cortex. The parietal region yielded significant differences whereas the central region did not. The original plan of the study was to use the temporal and parietal regions just as Galin and Ornstein [10] had done. During the pilot studies, much difficulty was encountered in placing the electrodes and getting artifact-free EEG recordings from the temporal region. On the basis of these results, the decision was made to use the central region, which is adjacent to the temporal region and does not produce the problems which are involved in using the temporal electrode placement. The central and parietal regions are both susceptible to muscular movements, the central region being the most affected by these. While the parietal and central regions are good recording sites, the temporal site must be considered on the basis of anatomical factors. In future studies

effort should be made to use the temporal region for electrode placement. Galin and Ornstein [10] cite evidence that the temporal region is the best for detecting asymmetries, with the parietal region the second best region. The temporal region is largely affected by verbal stimuli and the parietal by visual, spatial stimuli. Since these are the two most common methods of presenting tasks for analysis, these two regions are the most productive for this type of research. Butters and Barton [21] showed that damage to either parietal lobe of subjects impaired their performance on spatial orientations.

LIMITATIONS AND RECOMMENDATIONS

The basic limitations of this study were in the number and restricted range of intellectual development of the subjects. Many of the formal subjects scored at the low end of the range of scores classified as formal. It would be valuable to repeat this study with a larger number of concrete subjects similar to those used in the study and with some formal operational persons who are mathematics or science majors. The use of concrete subjects of college age may have masked greater differences between concrete and formal persons. These persons are considered by Piagetian theory to be abnormal because

they should have easily reached the formal operational stage by the time they are of college age. Although these college students were classified as concrete operational by the traditional Piagetian tasks, research needs to be done to compare them with younger concrete persons. The lack of previous research relating the EEG to cognitive functioning made it difficult to choose tasks and interpret the findings. For this reason, it would seem extremely important that basic research be conducted to establish the EEG characteristic of specific cognitive tasks. For example, it would be useful to design a study that would focus on the characteristics of the analytic mode of cognitive functioning. One of the important findings of the present study was that it did not show some of the distinct task differences characteristic of the work of Galin and Ornstein [10]. One possible explanation for this could be that they used a majority of formal subjects. Since this study found some significant differences between concrete and formal operational subjects, the stage of intellectual development of the subjects must be considered when evaluating past studies and when preparing future studies.

A last and most important recommendation involves the need to investigate interhemispheric activity. At

the present time it is not known how reliable EEG is for very short time intervals. For example, Galin and Ornstein [10] required thirty seconds of data for a task, while in this study shorter intervals were used. Since the subjects used in this study reversed hemispheric activity nearly every other second, it is critical to determine the reliability of short time intervals.

This exciting field of research has mushroomed in the fields of neuropsychology and medicine and it is time for education to begin applying it to the study of learning and teaching. It offers educators a research tool whereby cognitive activity can be studied in terms of hemispheric functioning.

Table 1

Logarithm of the Ratios (C_3/C_4) of the Average Task Powers, Means and Standard Deviations for Each Task for Each Group

Task	Concrete		Formal	
	Cell Size	Mean S. D.	Cell Size	Mean S. D.
Breathing	5	-.0339 (.1536)	6	-.0351 (.0500)
Arithmetic	5	-.0072 (.1401)	6	-.0290 (.1335)
Listening	6	.0378 (.2757)	6	.0368 (.1638)
Spatial	5	-.0059 (.1864)	6	-.0784 (.0896)
Conservation of volume	5	-.0045 (.2908)	4	-.0493 (.0548)
Analog	6	.0152 (1193)	5	.0351 (.0468)
Logic	6	.1719 (.1931)	6	-.0186 (.1105)
Overall Tasks	38	.0287 (.2038)	39	-.0196 (.1046)

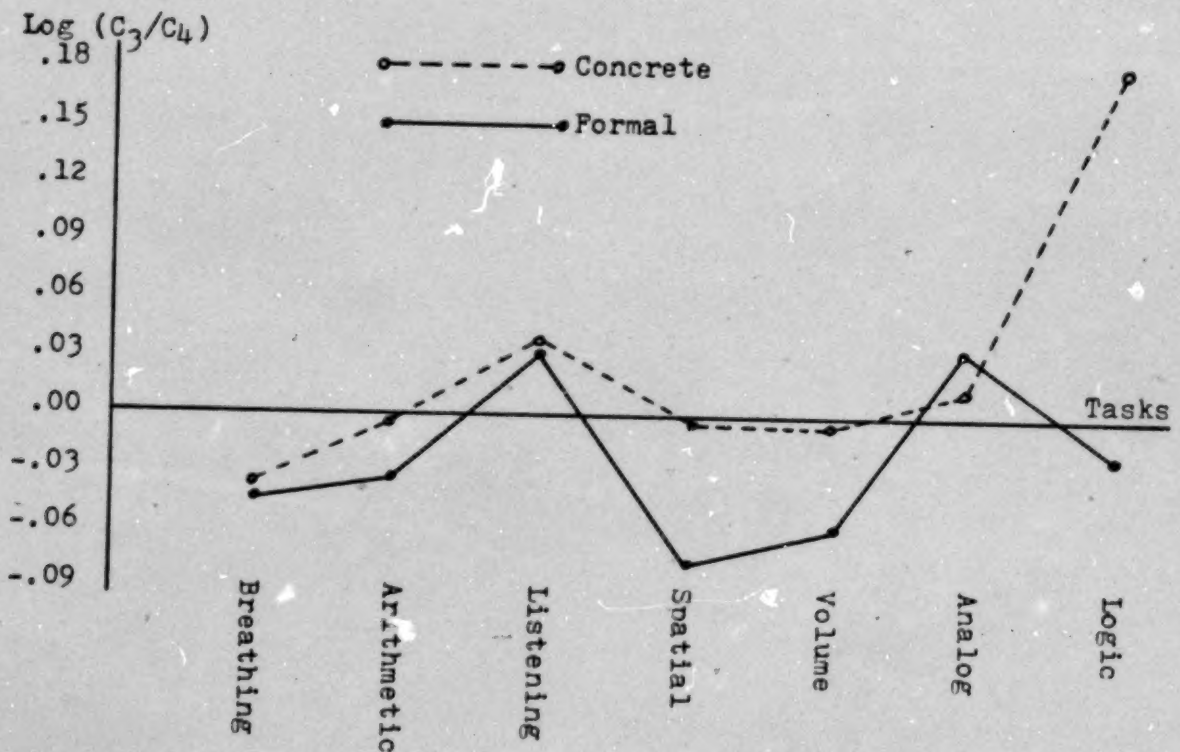

Figure 1

Plot of Logarithm of the Ratios (C_3/C_4) of the Average Task Powers Versus Tasks for Concrete and Formal Subjects

Table 2

Logarithm of the Ratios (P_3/P_4) of the Average Task Powers, Means and Standard Deviations for Each Task for Each Group

Task	Concrete		Formal	
	Cell Size	Mean S. D.	Cell Size	Mean S. D.
Breathing	4	-.0277 (.1333)	6	-.0829 (.1191)
Arithmetic	4	-.0313 (.0790)	5	-.1175 (.1587)
Listening	5	.0039 (.1335)	6	-.0264 (.1430)
Spatial	4	.0287 (.0370)	6	-.0409 (.1036)
Conservation of volume	5	.0079 (.1003)	5	-.0919 (.1249)
Analog	5	-.0489 (.0348)	5	-.0352 (.1168)
Logic	5	.0525 (.1230)	6	-.1044 (.0365)
Overall Tasks	32	-.0014 (.1004)	39	-.0706 (.1190)

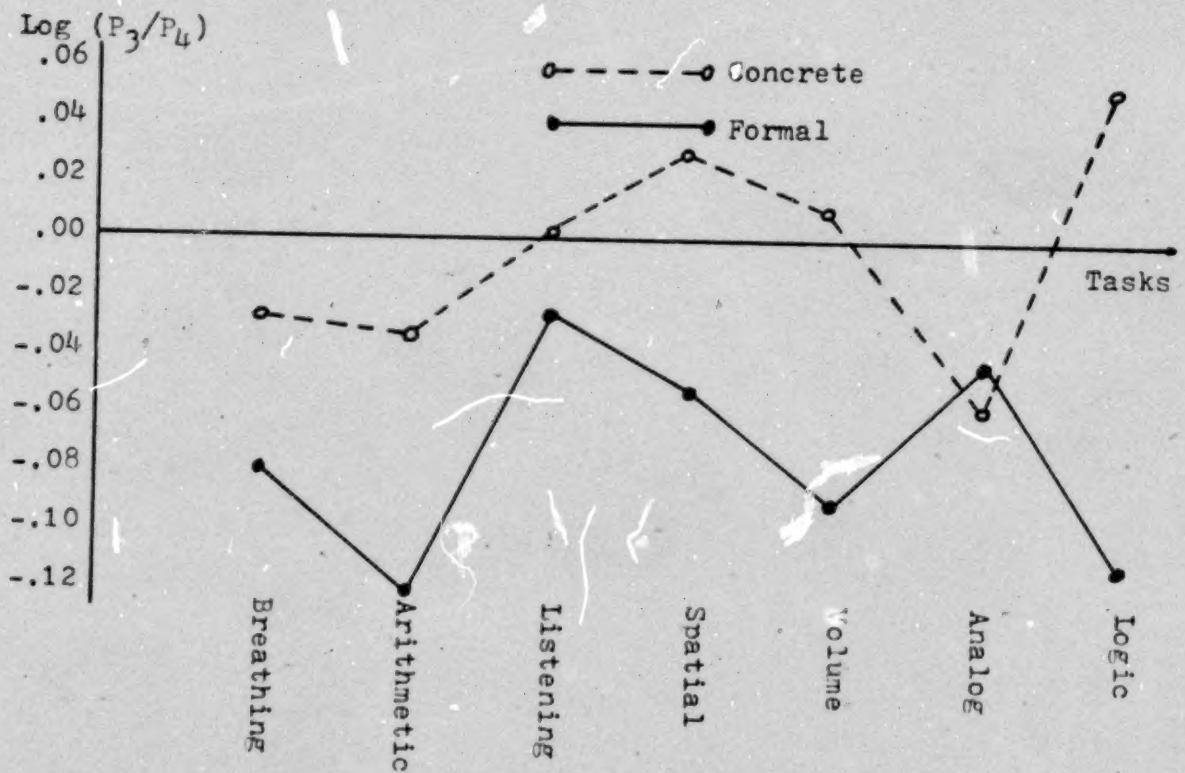

Figure 2

Plot of Logarithm of the Ratios (P_3/P_4) of the Average Task Powers Versus Tasks for Concrete and Formal Subjects

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